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(71) Applicant
GEC-Marconi Limited

(Incorporated in the United Kingdom)

The Grove, Warren Lane, Stanmore, Middlesex, HA7 4LY, United Kingdom

(72) Inventors
Duncan Peter Rowe
James Christopher Reynolds

(74) Agent and/or Address for Service
J Waters
GEC Patent Department, GEC-Marconi Research Centre, West Hanningfield Road, Great Baddow, Chelmsford, Essex, CM2 8HN, United Kingdom

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GB 2175705 A GB 2075762 A EP 0174008 A2
EP 0040302 A2 US 4793699 A

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(54) **Optical scanner having adjustable reflective elements in an array**

(57) An optical scanner comprises a plurality of reflective elements 4 arranged side by side to form an array, each element being supported by arms 11–14, the arms and the reflective elements being micro-machined e.g. from silicon. There are a large number of elements in the direction of arrow B and the size of each element is comparable with the wavelength of coherent radiation incident on the scanner.

The depth of the reflective elements 4 relative to the plane of the face of the scanner are adjustable e.g. by means of electrostatic attraction from electrodes 17 so that there is a progressive phase shift between an incident plane wavefront and the respective reflecting surfaces. Constructive interference then takes place at an angle to the original wavefront, enabling the beam to be steered.

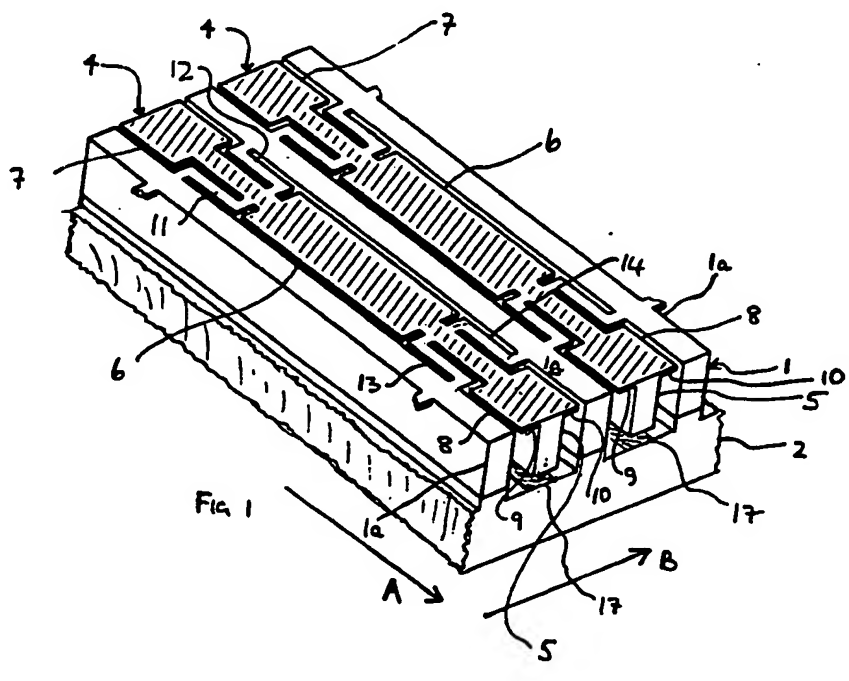

FIG. 1

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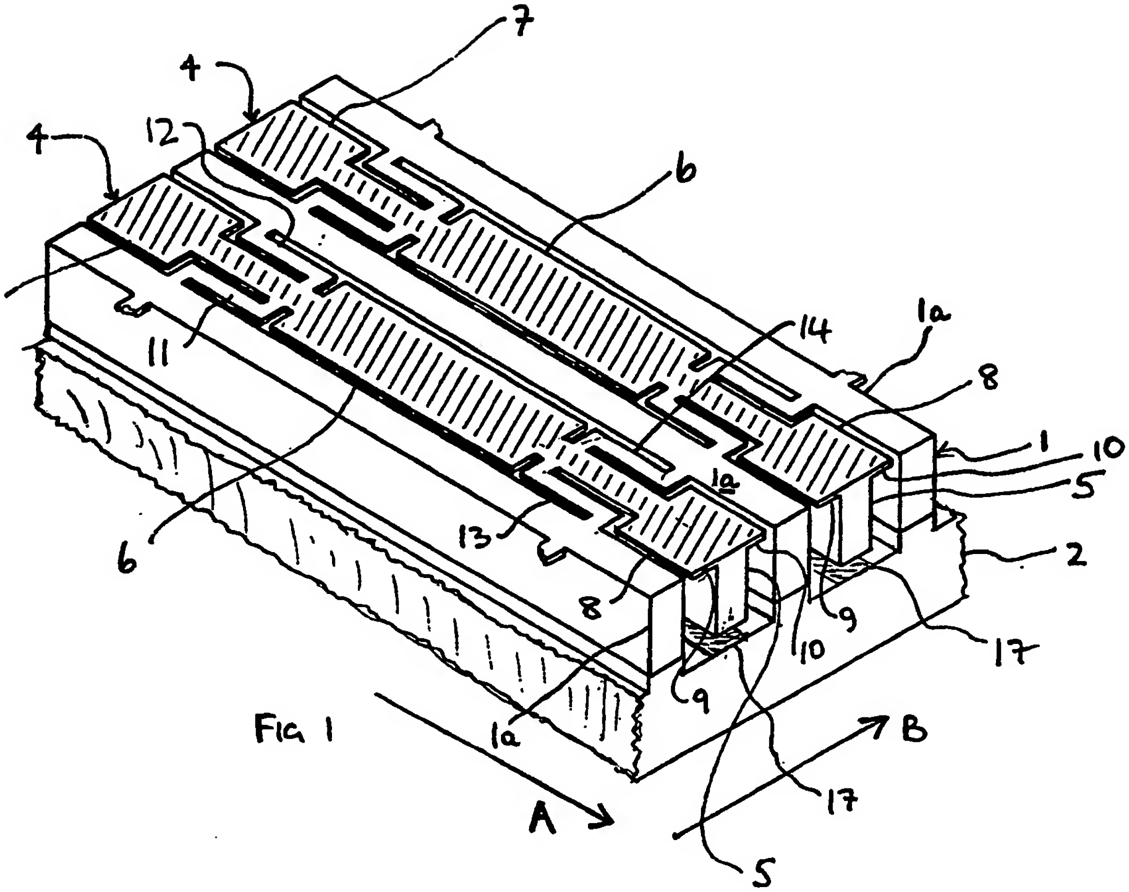

Fig 1

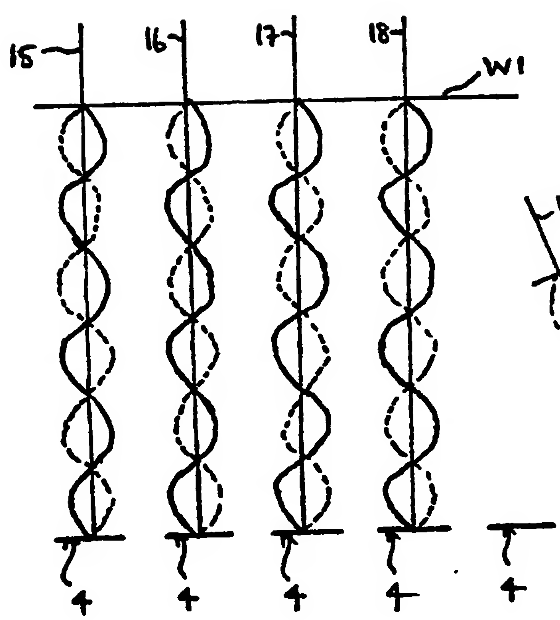

Fig 2

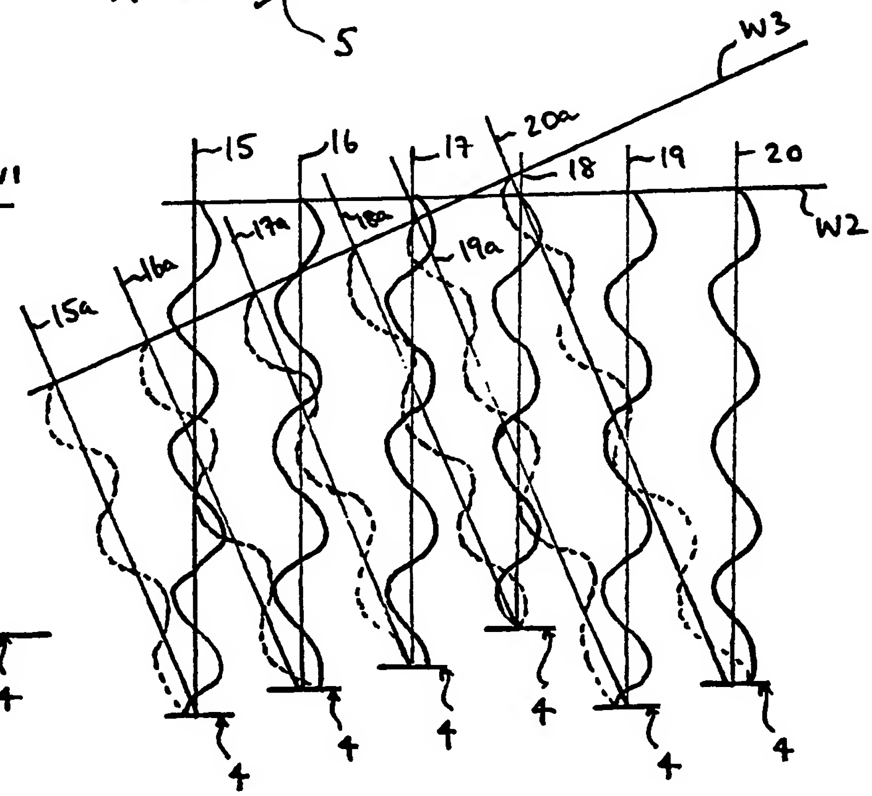

Fig 3

Optical Scanner

This invention relates to optical scanners.

The term optical as used herein, and term light, are not intended to refer only to visible electromagnetic radiation, but it is intended that ultra-violet and infra-red radiation should also be encompassed.

Such scanners are used in imaging systems. For example, in an active imaging system such as a laser radar, a laser beam is scanned over an area of scene in a raster. A scanner such as a mirror polygon or a "nodding" mirror is used to perform the line scan, and a further mirror or other optical element is used to displace the scanning laser beam from one line to the next. The light reflected from the scene is imaged using the same or another scanning system. Such scanners are also used in passive infra-red imaging systems, in which successive elements of a scene are imaged in a raster-like fashion.

Such scanners are frequently electromechanical in

nature and, due to the large apertures involved, have a high moment of inertia and hence a poor frequency response. Also, such scanners tend to be relatively bulky, which prevents their use in some applications.

The invention provides an optical scanner which comprises a plurality of longitudinaly-extending reflective elements arranged side by side to form an array, and means for adjusting the depths of the elements relative to the array.

The reflection of coherent light from the longitudinally extending elements may be made to interfere constructively in different directions depending on the relative depths of successive elements, enabling beam scanning to be accomplished in a small, low inertia, mechanism.

The reflective elements may be supported by arms arranged to bend to enable the depth of the elements to be adjusted and, preferably, both the reflective elements and the support arms are fabricated from a crystalline material such as silicon by means such as micro-machining.

The depth of the elements relative to the ray may be adjusted by means of an electrostatic force between the elements and another member.

An optical scanner constructed in accordance with the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a part of the scanner;

Figure 2 is schematic view of the scanner when all the elements are co-planar, seen in the direction of arrow A; and

Figure 3 is schematic view of the scanner when the elements are adjusted to steer the beam, seen in the direction of arrow A.

The optical scanner is formed of a part of micro-machined silicon indicated generally by the reference numeral 1 mounted on a substrate 2. The structure of the silicon and substrate repeats in the direction of the arrow B, two identical units only being shown. The widths of the units have been exaggerated in

Figure 1 for the sake of clarity, but in reality each is of the same order as the wavelength of infra-red radiation.

Each unit of the machined silicon has a longitundinally-extending reflective element indicated generally by the reference numeral 4. Integral with each element is a downwardly-extending beam 5 which extends the whole length of the respective element. Over a central region 6 and over over two end regions 7, 8, the upper face of the element overlaps the downwardly-extending portion on each side at 9, 10. This imparts rigidity to the reflective elements, keeping them optically flat whilst electrostatic forces are applied to displace them vertically.

Each reflecting element 4 is supported at two positions along its length by a pair of integrally formed longitundinally-extending arms 11, 12, 13, 14 which secure each element to a pair of longitundinally-extending support beams 1a. The separation of the support regions is chosen to minimise droop in the reflective elements.

Each unit also has an electrode 17 plated onto a

substrate, but electrically isolated from it, beneath each downwardly-extending beam. Means (not shown) is provided for applying a potential to each electrode, the remainder of the scanner being at ground, causing an electrostatic attractive force between each downwardly-extending beam and the electrode on the substrate. Variation of the potential on any electrode varies the electrostatic attraction, and the reflective element as a whole is displaced downwardly relative to the plane of the array. The depth of each element may be adjusted to any desired value in this way, between the position shown in the drawing in which the reflective elements are co-planar with the plane of the array, and a position in which the downwardly-extending beam is near to the respective electrode. When the reflective element is displaced downwardly, the arms 11 - 14 deflect accordingly, that the face of the element remains flat.

The effect of adjusting the height of the respective elements is illustrated in Figures 2 and 3, in Figures 2 and 3, coherent light is incident on the reflective elements normally. In Figure 2, coherent radiation from a laser illuminates the elements, and so the radiation along paths 15 - 18 is in phase with each

other at wavefront W1. To simplify matters wavefront W1 is shown as being three complete wavelengths away from the reflective elements 4. Light is diffracted from the elements, each acting as a line source. The returning wavefront will also be shown by W1 since the scattered light from each element will be in phase with each other along this line. The incident are beams are shown as full waves and the reflected beams are shown as dotted waves. Again there will be three complete wavelengths between the reflecting elements and the wavefront W1.

Referring to Figure 3, the reflective elements are no longer co-planar. The path lengths between the wavefront W2 and each element are now different. Again, each element acts as a line scattering source, and the waves from the scattered radiation will be in phase along a line such as W3 which is no longer parallel to W2. The incident rays 15 - 20 have thus been reflected through an angle to form the reflected rays 15a - 20a. Again the incident waves are shown in full line and the reflected rays are shown in broken line.

It is of course necessary for the depth of each element relative to the preceding one to be equal, representing an equal phase shift, in order that the

waves in the scattered rays are in phase over a line to form a uniform wavefront. It is not, however, necessary for the depth to increase gradually over the whole of the width of the scanner. The depth of the elements could simply repeat, as shown in Figure 3, provided that the phase difference between the path from wavefront W2 to the fifth element from the left and the path from the wavefront W2 to the fourth element from the left, is the same as the phase difference between the path from the wavefront W2 to the fourth element from the left and the path from the wavefront W2 to the third element from the left, and so on. The only criteria necessary to enable this to happen is that each reflective element is displaceable by a depth equal to a wavelength of the radiation with which it is to be used.

By varying the relative depths of the elements, the angle of wavefront representing in-phase reflections is changed and the angle of reflection is accordingly changed. If the depth is varied continuously to the appropriate degree, the incoming beam can be steered i.e. scanned to produce a range of angles of outgoing beam. Further, because of the rapid response and low moment of inertia, the steering can be varied between widely spaced angles without passing through all the

angles in between i.e. the scanner can be used in applications calling for agile scanning.

The micro machining is carried out in the following way.

A crystal of silicon is doped with a suitable impurity (e.g. boron) over its entire upper surface. This is etched through a mask (e.g. by plasma etching) to produce the slots shown on the surface in Figure 1. The exposed silicon is then etched through the slots by an anisotropic etchant (e.g. KOH) which does not attack the doped region. The silicon crystal is orientated so that it is etched preferentially downward and in the direction of the arrow A, little etching occurring in the direction of the arrow B. A rectangular hole is thus produced, whose dimensions correspond to the dimension of the slots in the direction of the arrow B and the length of the elements in the direction of the arrow A. Figure 1 shows such a hole, with the arms 11 - 14 and overlapping portions 9 - 10 remaining as they consist of doped silicon, the downwardly extending beam 5 and support region 1a remaining as they are outside the area described by the slots. The upper faces of the elements are then coated with a reflective coating.

The micro-machined structure is then connected to the substrate, which can also be formed by etched silicon.

Typical dimensions of the scanner shown, suitable for use with CO_2 infra-red laser are: length (direction of arrow A) 50mm, width (direction of arrow B) 50mm. The width of each unit (direction of arrow B) could be 10 microns, so that there would be 5,000 elements arranged side by side in the array. The clearance between the bottom of the downwardly extending beam 5 and the electrode 17 could be 100 microns, and the height of each beam could be 0.25mm.

Of course, variations may be made to the above embodiment without departing from the scope of the invention. Thus, the arms 13, 14 could be identical to the arms 11, 12, rather than extending in opposite directions to them. And further pairs of arms could be provided if desired. The support beams 1a could be replaced by pillars and the reflective elements could be widened on each side of the pillars to provide only a small clearance between them. The structure shown in Figure 1 could be made smaller in the direction of arrow

A, and repeated a number of times e.g. the total length in the direction of the arrow A of the reflective elements illustrated could be reduced to 5 mm, but ten identical elements could be provided end to end. Wavelengths other than infra-red could of course be used.

Also, the micromachined silicon could be inverted, leaving the base 2 in the orientation illustrated, and the reflective coating would then be applied to the beam 5 rather than in the position illustrated, i.e. the lower surface of the beam 5 as illustrated would become the upper reflective surface.

Further, it would be possible to reduce the length of the elements 4 (in the direction of the arrow A), keeping the width (in the direction of the arrow B) the same, to such a point that the length of the elements became equal or approximately equal to the width. Having done that, a square array could then be made up by providing a large number of identical structures extending in the direction of the arrow A. With the examples of dimensions given above, 5000 such structures in the direction of arrow A would be required. The advantage of such an array would be that beam scanning could be carried out in two directions at right angles.

That is, the elements in each column (extending in the direction of the arrow A) made up of the large number of square elements could also move in unison and at the same depth, so that the structure acted in the same way as that illustrated in the drawing. Or, the elements in each row (extending in the direction of the arrow B) formed by the telescoping of the illustrated embodiment, could move in unison and at the same depth, so that beam scanning would take place at right angles to that for the original illustrated embodiment. Or by varying the depths of the elements along the columns (direction A) and along the rows (direction B), scanning in an intermediate direction could be accomplished. Such a structure could also be used to bring the reflected light to a focus, if the phase differences of reflected waves from adjacent elements were not constant across the array but varied in the manner of a Fresnel lens. The depths of the elements could be varied so as to change the focal length or to scan the focus through an angle as described above. Similarly, in the original embodiment of Figure 1, the depths of the elements could be adjusted so that the embodiment acted as a cylindrical Fresnel lens, and again the depths of the elements could be varied to change the focal length or to scan the focus through an angle. For the avoidance

of doubt, changing the focus of the reflected beam, or changing its angle, or both, are intended to be encompassed by the term scan as used herein, and the term optical scanner should be interpreted accordingly. The means for adjusting the depths of the square elements need not be electrostatic, but could be piezo-electric and this could also be used in the original embodiment shown in Figure 1.

CLAIMS

1. An optical scanner which comprises a plurality of reflective elements arranged to form an array, and means for adjusting the depth of the elements relative to the array.

2. An optical scanner as claimed in claim 1, in which the adjusting means is arranged to impart to a coherent incident beam the same relative phase difference between successive elements across the array, the phase difference being variable to scan the beam.

3. An optical scanner as claimed in claim 1, in which the adjusting means is arranged to impart to a coherent incident beam such relative phase differences between successive elements across the array that the array acts as a lens.

4. An optical scanner as claimed in any one of claims 1 to 3, in which the array is formed of reflective elements arranged in rows and columns.

5. An optical scanner as claimed in any one of claims 1 to 3, in which the array is formed of longitudinally-extending elements arranged side by side.

6. An optical scanner as claimed in claim 5, in which each of the elements is supported by an arm, the plane of which is parallel to that of the reflecting surface of the respective element, the arm being arranged to bend to adjust the depth of the respective element.

7. An optical scanner as claimed in claim 6, in which the arm extends in a direction parallel to the element.

8. An optical scanner as claimed in claim 6 or claim 7 in which the arm and the elements are etched from a crystalline material.

9. An optical scanner as claimed in claim 8, in which one face of the arm and elements is doped and the undoped regions have been etched away to form the arm.

10. An optical scanner as claimed in any one of claims 1 to 9, including means for generating an

electrostatic force on the elements to adjust their depths relative to the array.

11. An optical scanner as claimed in any one of claims 1 to 10, in which the extent of the reflective elements is less than 100 microns in one direction.

12. An optical scanner as claimed in claim 11, in which the extent is less than 25 microns.

13. An optical scanner substantially as hereinbefore described with reference to the accompanying drawings.

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